MCNPX Cosmic Ray Shielding Calculations with the NORMAN Phantom Model

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INTRODUCTION

The United States is planning manned lunar and interplanetary missions in the coming years. Shielding from cosmic rays is a critical aspect of manned spaceflight. These ventures will present exposure issues involving the interplanetary Galactic Cosmic Ray (GCR) environment. GCRs are comprised primarily of protons (~84.5%) and alpha-particles (~14.7%), while the remainder is comprised of massive, highly energetic nuclei. The National Aeronautics and Space Administration (NASA) Langley Research Center (LaRC) has commissioned a joint study with Los Alamos National Laboratory (LANL) to investigate the interaction of the GCR environment with humans using high-fidelity, state-of-the-art computer simulations. The simulations involve shielding and dose calculations in order to assess radiation effects in various organs.

The simulations are being conducted using high-resolution voxel-phantom models and the MCNPX[1] Monte Carlo radiation-transport code. Recent advances in MCNPX physics packages now enable simulated transport over 2200 types of ions of widely varying energies in large, intricate geometries. We report here initial results obtained using a GCR spectrum and a NORMAN[3] phantom.

COSMIC RAY SPECTRUM

Our initial work has involved the use of measured 1977 GCR[2] data to create a representation suitable for use with MCNPX. The particle constituency encompasses all components from protons to ^{58}Ni. Each isotope has been assigned a fractional contribution and an energy spectrum[2].

For our simulations, this source was placed uniformly around a phantom geometry and inwardly directed with a cosine sampling distribution. The source was normalized to produce an overall GCR flux of 4 particles/cm^2-s.

NORMAN PHANTOM MODEL

The NORMAN phantom is a high-resolution (~2 mm/side) voxel representation of a Caucasian-type adult male that was developed at the National Radiation Protection Board using data obtained from magnetic resonance imaging[3]. For our initial studies, the upper-torso portion of the full NORMAN model has been used.

The upper-torso NORMAN voxel phantom is a 35-MB, 15273459-voxel model. Figure 1 contains an MCNPX plot view of the model; various anatomical regions are recognizable.

Fig. 1. Ventral slice from NORMAN phantom.

CALCULATION

The calculations were performed with MCNPX v2.6.0 using the heavy-ion feature [4] and the LAQGSM 3.01[5] physics model. The GCR source was directed inwards towards the phantom geometry passing through a thin layer (2.0 g/cm^2) of aluminum (not shown in Fig. 1). A tally of total energy deposition was performed in the bone material. This tally was subdivided by the contributions caused by the initial particle types in the GCR spectrum.

RESULTS

The results shown in Fig. 2 depict the relative energy deposition as a function of particle mass for each type of particle in the GCR spectrum model. The energy deposited has been scaled by the frequency and mass of the particle.
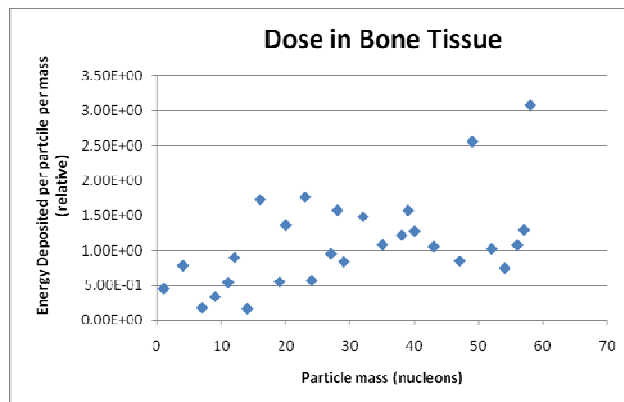
Fig. 2. Energy deposition from each particle in GCR spectrum.

The results suggest an overall trend of increasing energy deposition as a function of increasing particle mass, both relative to mass and the fractional particle contribution in the source, especially when compared to the proton and alpha particle that dominate the source term.

CONCLUSIONS

MCNPX has been used to conduct initial shielding and dose calculations involving the interaction of GCRs composed of particles ranging between protons and ^{58}Ni with a high-resolution voxel model of an adult male. Preliminary results indicate that energy deposition increases as a function of particle mass. This work is being conducted in support of a joint NASA-LaRC/LANL study involving the interaction of GCR radiation with humans as preparation for manned lunar and interplanetary spaceflights.

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